NASA Earth Science Applied Sciences Program

National Application - Air Quality

Benchmark Report

Biomass Burning Emissions Enhancements for Air Quality Planning

October 2007

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Overview

This benchmark report describes work completed in cooperation between National Aeronautics and Space Administration (NASA), the Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) to improve the timeliness, accuracy and cost of biomass burning emissions to the National Emissions Inventory (NEI) in an effort to improve air quality and assessments of air quality. The ultimate goals of this project are to first understand the customers NEI process and data needs and then demonstrate the capability and usefulness of NASA earth science fire data to the NEI.

The EPA, in its mission to protect human health and the environment, is mandated to ensure the nation's air is breathable for current and future generations. Under the Clean Air Act, the Office of Air Quality Planning and Standards (OAQPS) is responsible for setting standards for pollutants that are considered harmful to people and the environment, and these are known as the National Ambient Air Quality Standards (NAAQS). A key tool in EPA's arsenal is the National Emissions Inventory (NEI), which is a national database of air emission information of each area of the country, compiled by EPA on an annual basis. It contains information on stationary and mobile sources that emit criteria air pollutants and their precursors, as well as hazardous air pollutants. The NEI is used for a number of critical environmental management and policy activities including regulation setting and regional strategy development for attainment of the NAAQS. The gridded NEI files that include fire emission estimates are ingested by the Community Multiscale Air Quality (CMAQ) model emissions processor, which is also widely distributed and used as a Decision Support System (DSS).

Air Quality and Biomass Burning Emissions

In 1990, Congress amended the Clean Air Act (CAA) to require the United States Environmental Protection Agency (EPA) to address regional haze. Regional haze refers to visibility impairment that is caused by the emission of air pollutants from numerous sources located over a wide geographic region that may encompass several states. The EPA Office of Air Quality Planning and Standards (OAQPS) published a rule in 1999 to address regional haze in 156 Class I areas, which include national parks and wilderness areas such as the Grand Canyon, Yosemite, the Great Smokies and Shenandoah [*Federal Register*, 1999]. The rule requires the states, in coordination with the EPA, the National Park Service, U.S. Fish and Wildlife Service, the U.S. Forest Service, and other interested parties, to develop and implement State Implementation Plans (SIPs) to reduce the pollution that causes visibility impairment. Additional information concerning the regional haze program can be found at the EPA's website: http://www.epa.gov/air/visibility/program.html.

As a result of the Regional Haze rule, five Regional Planning Organizations (RPO) were formed across the United States in an effort to coordinate affected states and tribes and to initiate and coordinate activities associated with the management of regional haze and other air quality issues. The five RPOs are: the Central Regional Air Planning

Association (CENRAP), the Midwest Regional Planning Organization (Midwest RPO), the Mid-Atlantic and Northeast Visibility Union (MANE-VU), the Visibility Improvement State and Tribal Association of the Southeast (VISTAS), and the Western Regional Air Partnership (WRAP). The RPOs are tasked with, among other things, assisting the States in the development of regional haze SIPs. These SIPs, due by December 17, 2007, must include long term strategies to control regional emission sources, with the goal of returning to natural visibility conditions at 156 Class I areas by 2064.

Biomass burning (wildfire, prescribed burning and agricultural burning) is one of the primary causes of elevated airborne particulate matter, ozone precursors and regional haze. However, biomass burning is perhaps the most poorly documented emission source, even though burning impacts several major EPA air programs and is a significant contributor to air pollution (PM, ozone precursors and regional haze), particularly on the 20% worst air quality days [*Kittaka et al.*, 2004; *Malm et al.*, 2004].

Haze-causing pollutants (mainly $PM_{2.5}$ - particles 2.5 microns or less in diameter) are directly emitted to the atmosphere and formed secondarily through the combination of smaller precursor particles. Activities that can lead to the formation of $PM_{2.5}$ include electric power generation, various industrial and manufacturing processes, truck and auto emissions, construction activities and biomass burning. Biomass burning is a major source of $PM_{2.5}$, consequently regional haze, and it is poorly quantified.

The inability to adequately define biomass emissions is due to the fact that the United States does not have a standard database of fire events or area burned for any year. Several organizations (i.e. U.S. Forest Service, Bureau of Land Management) have limited data for their particular geographic regions, but these data are not collected by a standard methodology, even within an organization. Additionally, these data exclude any biomass burning events that occur outside of these boundaries and often fail to capture agricultural burning (e.g., sugar cane, wheat/rice stubble, and grasses).

Previous EPA methodologies for estimating biomass burning emissions lack geospatial location and involve the use of fire activity data from a variety of sources and the application of ratio methods or growth factors when current year data are not available or incomplete. Fire-related emission estimates are only spatially and temporally resolved to the monthly scale for all states based on the climatology of the region [*EPA*, 2004]. EPA methodologies, which aggregate biomass burning and fuel load data, have been found to often lead to large errors and inaccuracies when comparing where emissions are shown to occur and where actual biomass burning occurred [*EPA*, 2001]. These uncertainties affect the accuracy and reliability of simulations for Air Quality (AQ) forecasting and for AQ management assessments.

In addition to the shortfalls noted above, the funding required (additional $1 million) and time needed to develop fire emissions estimates is a critical shortcoming of the current NEI. Currently, the NEI is compiled approximately 24 to 36 months after the end of a fire season. It takes many months to merge and quality assure the dozens of datasets that contain fire event data. The NEI is currently being re-engineered to provide a product in 12 months, starting with the NEI for 2008. Thus, the ability to provide fire emission estimates much more quickly is crucial to the success of the NEI re-engineering effort.

Benchmark Intent

This benchmark work supports EPA's goal of improving biomass burning emissions estimates to the NEI by providing sound research in coordination with the EPA. Improvement in biomass emissions is an area where improvements are essential to regulation setting, regional strategy development for attainment of NAAQS and ultimately to improve human health. Additionally, these activities directly and indirectly contribute to the goals and objectives of the NASA Applied Science Program National Air Quality Priorities, the recent Decadal Survey and to the visions of US GEO strategic plan by using NASA, NOAA, and EPA science and technology to inform and advance a significant national EPA Decision Support System tool, the NEI.

Approach

The first goal of this project was to understand the customers NEI process and specific data needs, which was accomplished through several scientist to regulator, scientist to customer and scientist to scientist conversations. These conversations evolved as the project advanced, and the primary purpose of this project became establishing customer confidence in satellite-based fire data, which was accomplished through continual data analysis, communication and presentations in meetings, workshops and conferences.

The EPA focuses on producing a detailed NEI every 3 years, and in 2002, a substantial amount of time and monetary resources were expended to produce the best available ground-based fire dataset in existence for the United States. This project was specifically designed to compare satellite-based area burned data products to EPA's "trusted" 2002 ground-based inventory to establish credibility in satellite data using the dataset in which the EPA is confident.

Because the EPA is responsible for the development of the NEI, the EPA requires knowledge of the spatial and temporal ability of satellite-based fire data and its associated potential error. Additionally, the EPA requires a methodology that will be consistent into the future, so the investigations that led to this report focus on satellite data that has been consistently available and predicted to be available in the future. Without an understanding of the capability of satellite data to describe the spatial, temporal and size domains of fire in the United States, emission estimates using these data are uncertain.

Detailed methodology is described in several EPA reports and in peer-reviewed publications [*Soja et al.*, 2005; *Soja et al.*, 2006; *Soja et al.*, 2007; *Al-Saadi et al.*, in review; *Soja et al.*, in review], so the focus of this report will be on the results of this collaborative project. With that said, throughout these investigations, NASA and NOAA satellite data are used to assess the relationship between satellite and ground-based fire data and to assign statistical relationships between these data. Two satellite-derived products were considered, one based on Geostationary Operational Environmental Satellite (GOES) Automated Biomass Burning Algorithm (ABBA) data and the other on MODerate Resolution Imaging Spectroradiometer (MODIS) thermal anomaly data.

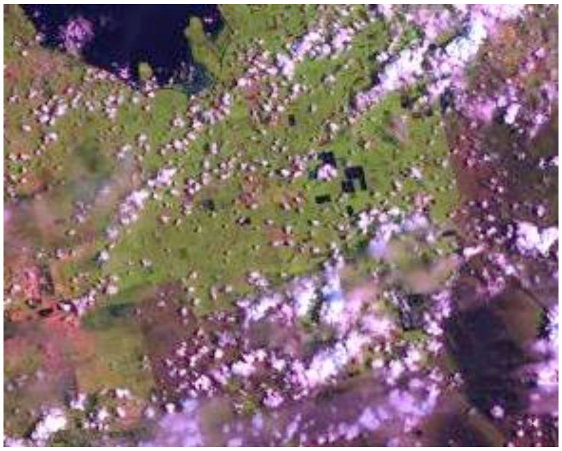
Verification of Fires in Florida

Our first objective was to demonstrate that satellite data was capable of detecting fires that were not reported in the NEI [*Soja et al.*, 2005]. MODIS and GOES satellite products identified 2407 fire events and the ground database holds 4342 fire events, some of which may have been too small for the imagery to detect. We demonstrated that satellite data were spatially coincident with 14% of the reported ground fires, however we considered this an underestimate due to geolocation issues (discussed below). When buffered to their respective spatial resolutions, the satellite imagery was able to define 54% of the representative area within the ground fire database. Representative area is the area reported burned in the ground-based data for each fire a satellite identifies.

Subsequently, we used Enhanced Thematic Mapper imagery to identify fires that MODIS and GOES satellites were detecting fires that were not reported in the ground-based data (figure 1). In many ways, this was a learning experience for the EPA, NOAA and NASA, as inconsistencies in the ground truth data revealed themselves and the unexpected unique value of satellite data also revealed itself. For instance, during this initial investigation of Florida and parts of the southeast, we discovered differences in NEI reporting varied substantially by region (county, state, county centroid reporting) and between the type of data recorded (agricultural, pile) within each region. We concluded with a recommendation for more rigorous examination of the data. Following this initial assessment, we had the attention of the EPA emissions community and were enthusiastically invited to continue our joint work.

Analyses of Oregon and Arizona

The goal of these analyses was to quantify the number of fires and the amount of area burned that was coincident in the satellite- and ground-based data in an effort to assign statistical error and provide essential confidence in these data. We focused on distinct ecoregions. Oregon is defined by a cool, dark vegetation-filled background that typically enhances the satellites ability to detect fire, and Arizona is a reflective (sand, minerals), hot environment that challenges satellite fire detection. For instance, GOES classified 85% of the fires as low probability flag 5 data in Arizona, as compared with GOES data from Oregon that classified 14% of the data as flag 5 low probability.



1b. July 20, 2002

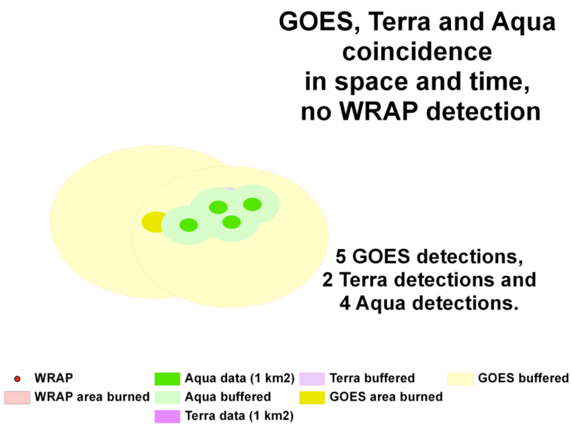
1a. August 5, 2002

1c. May 15, 2002.

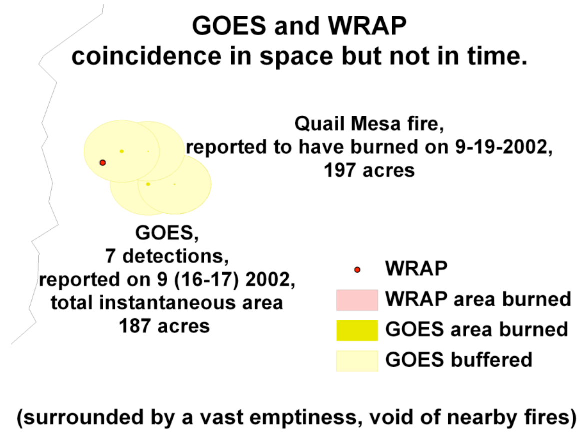
1d. June16, 2002.

Figure 1. Enhanced Thematic Mapper (ETM) data sensed agricultural burning near the Everglades that was not reported in the NEI (1a and 1b). Several more fields were burned in the later image, which coincides with MODIS imagery (shown in another figure [*Soja et al.*, 2005]). ETM near Okefenokee Swamp (1c and 1d). The fire scar is enlarged in the June 16th image, and the location of these scars coincides with GOES imagery, however the fire is not recorded in the ground fire data.

As previously noted, this was an iterative analysis that developed over time. Initially, exact date and spatial coincidence was analyzed [*Soja et al.*, 2006]. Because this analysis identified significant differences and, at times, errors in the NEI (figure 2), the date range of the coincidence analysis was expanded to exclude some of the errors in reports submitted to the inventory [*Soja et al.*, 2007]. The following analysis is from the latest 2007 report that accounts for some of the discrepancies. Still, because of inconsistencies, we believe the coincidence analysis is not representative of coincident reality.



2a.



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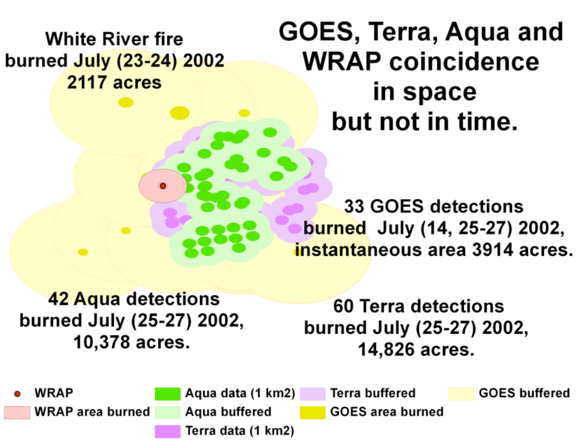

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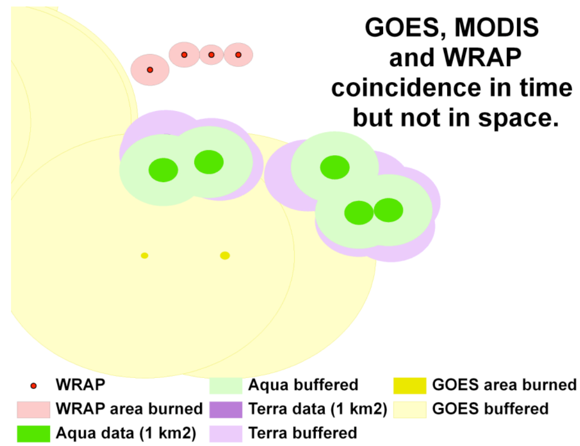


2d.

Figure 2. Examples of discrepancies between satellite and ground based data. MODIS aqua data are green; MODIS Terra data are lavender; GOES data are wheat; and ground-based data are shown in red. The lighter colored regions are buffers surrounding the data, which are used solely to associate the spatial domain of the satellite data with the ground-based data. Light rose surrounding the ground-based data represents the amount of area burned, as reported in the database. Numerous rings represent the area reported each day, which is consistently reported at the point of ignition. 2a. Each of the satellites detected a fire within the same timeframe, however there is no fire recorded in the ground-based data. 2b. The spatial domain is coincident but the timeframe is not coincident, so these fires would not be considered coincident, even though they are most likely coincident fires. 2c. The satellites are coincident with the ground fire in space but not in time. 2d. Satellite and ground data are coincident in time but not in space. There are several reasons for these discrepancies. For one, fire fighters often have more timely concerns than immediately recording these data (i.e. safety and property). Also, several agencies do not report fires that burn < 100 acres per day, and satellite data often capture these fires.

In general, each of the satellite instruments are able to capture a large portion of the representative area burned and the spatial domain of the fires. The spatial domain of a fire is captured by satellites as a fire burns and moves over time, and this information is not recorded in current ground-based data (ignition point source) as shown in figures 2 and 3. Representative area is the area reported burned in the ground-based data for each fire a satellite identifies. The combined satellite data capture 69% of the representative area burned in Arizona and 97% of the representative area burned in Oregon.

We demonstrated satellite data competently identify large fire events, but the relationship is not as strong for small fires. Additionally, MODIS data are more likely to capture area burned by medium to large wildfires, and GOES data are more likely to detect small, short-lived agricultural fires. Coincident area burned data correlates well, however each MODIS instruments fire detections typically overestimate area burned, and GOES instantaneous area underestimates area burned in comparison to ground data (figures 4 and 5).

In Oregon, MODIS instruments aboard Terra and Aqua are capable of detecting 37 and 43% of the number of non-agricultural fires, respectively. However if one considers a fire detection equivalent to 1 km^2, Terra and Aqua detect 131 and 98% of the total area burned by these fires, respectively. In contrast, GOES (aggregated instantaneous area) is able to detect 34% of the number of non-agricultural fires but only 32% of the area burned. In combination, all the satellites are able to detect 53% of the total number of fires and 262% of the area burned by all fires (MODIS detect = 1 km^2).

MODIS instruments capture a limited number of agricultural fires, because the timeframe Aqua and Terra are overhead is limited and often not when the agricultural fires are burning. Even though GOES substantially underestimates area burned by agricultural fires, the instruments accurately capture the spatial and temporal domain of agricultural fires.

In Arizona, coincidence analysis demonstrates GOES identifies 5% of the total number of fires and 33% of the total area burned. Terra and Aqua identify 15 and 12% of the total number of fires, respectively, but 141 and 139% of the total area burned (MODIS detect = 1 km^2), respectively. All satellites combined are able to detect 22% of the total number of fires that burned in this region. Nonetheless, combining all satellite data (MODIS detect = 1 km^2) results in an overestimate of the total area burned (220%).

The research demonstrates satellites are able to capture most of the largest fires in Arizona (representative area 69%) and Oregon (representative area 97%), and this accounts for most of the area burned and biomass emissions. In Oregon, 80% of the area burned can be defined with the largest 10% of the fires, and in Arizona, 74% of the area can be defined with the largest 10% of the fires. This relationship is consistent in Florida [*Soja et al.*, 2005], where in the wildfire database, the largest 1% of the fire events account for 75% of the total area burned.

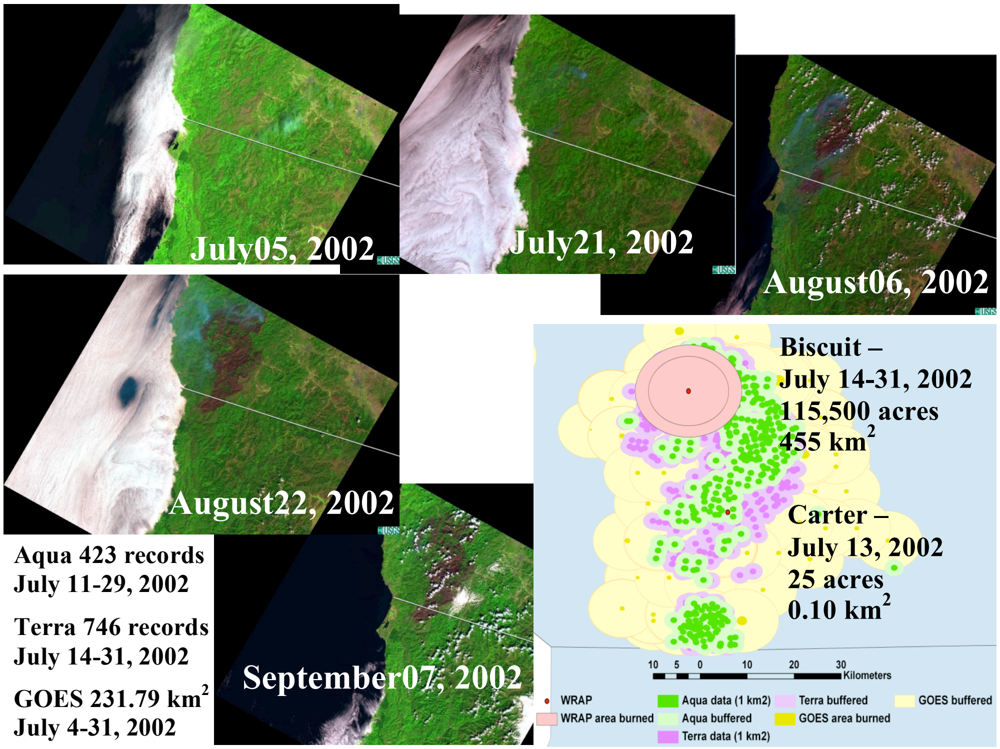


Figure 3. Evolution of the Biscuit fire over time. Enhanced Thematic Mapper pictures are provided to show the shape of the fire scar. Satellite data are able to accurately define the movement of the fire as it burns over tine, unlike the ground-based data, which is reported at the ignition source. Satellite and WRAP fire records represent only those recorded in July, 2002, not the entire area burned during the Biscuit fire.

Alaskan Analysis

We took advantage of the INTEX-NA field campaign to test our ability to estimate and transport biomass burning emissions based on satellite and ground-based data [*Soja et al.*, in preparation]. The field campaign coincided with an Alaskan fire season that was the largest in over 55 years of record. Alaskan fire data is unique because perimeters are recorded, as well as area burned, which allowed for a complete error assessment. GOES data does not completely capture fire at these latitudes, so the analysis is limited to MODIS data. MODIS data (Terra and Aqua combined) captured 86% of the number of fire scars and accounted for 108% of the total area burned (assuming MODIS detect = 1 km^2). The scars that are missed are generally less than 1 km^2 (largest undetected scar 4.56 km^2). Additionally, MODIS data spatially replicated the fire scars (figure 6), and commission (6.78% of the number of fire scars and 0.31% of the area burned) and omission errors (14% of the fire scars and 0.08% of the area burned) were remarkably low. Coincident MODIS and ground data also compared well as shown in figure 7. MODIS data competently quantified area burned using fire detections in Alaska. However, these fires were extremely large and fast moving, unlike most fires in the continental United States (CONUS). For instance, the Oregon biscuit fire, analyzed here, is one of the larger fires in CONUS.

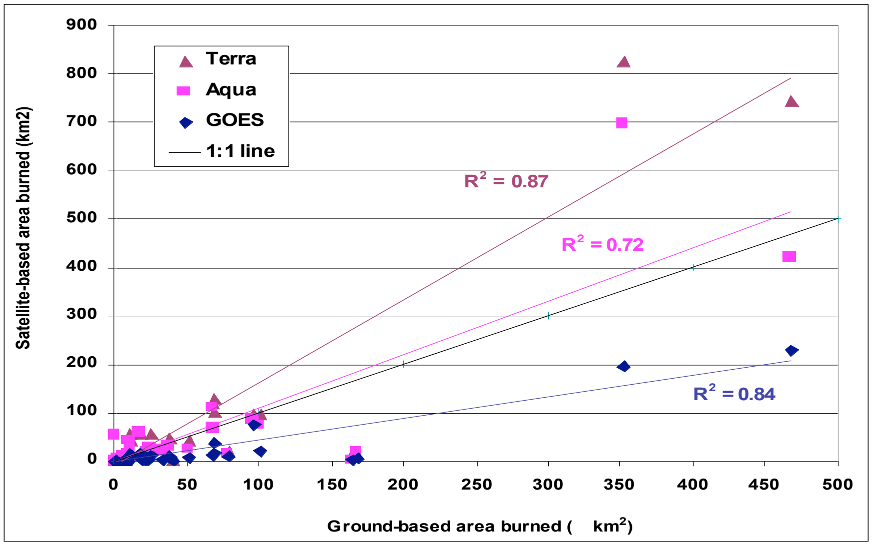


Figure 4. Comparison of coincident satellite and ground-based area burned data for Oregon, July 2002. Individual coincident fire data show good correlation, however one must note the differences in the axes. Even though the data correlate well, GOES data underestimates area burned, and both Terra and Aqua (detections) individually overestimate area burned, substantially if the instrument detections are combined.

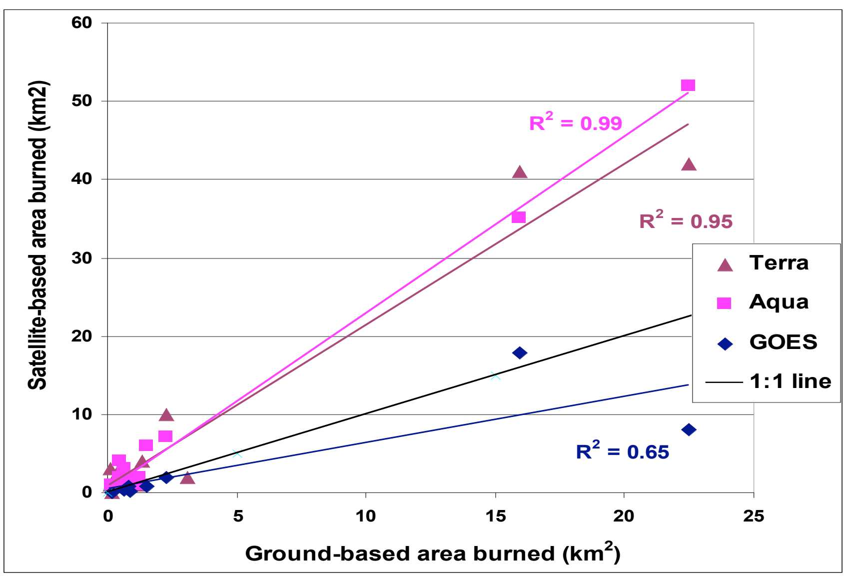
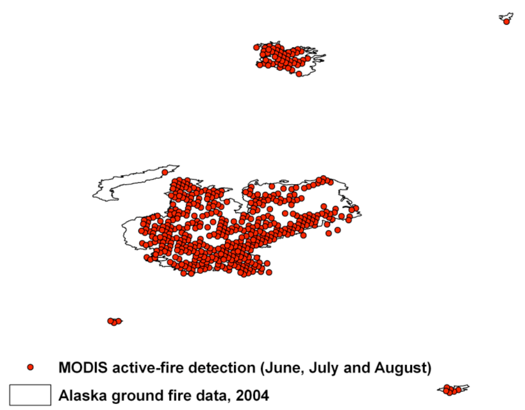
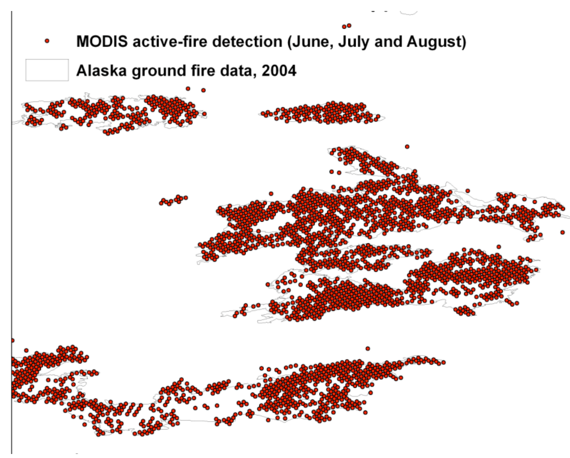
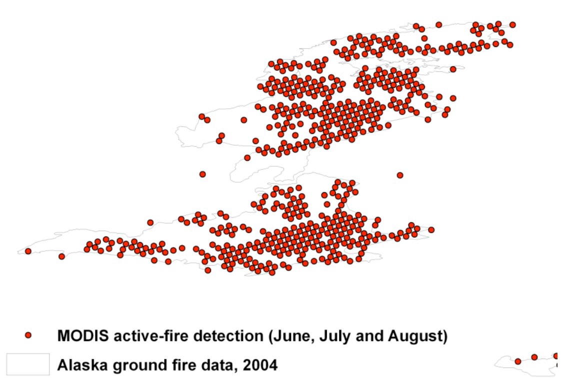


Figure 5. Comparison of coincident satellite and ground-based area burned data for Arizona (August and September 2002). Same as figure 4.

Next, biomass emissions are calculated using satellite data, carbon consumption maps and Haines indices [*Soja et al.*, 2004; *Al-Saadi et al.*, 2007; *Soja et al.*, in preparation]. These data are assimilated by the NASA LaRC-University of Wisconsin Regional Air Quality Modeling System (RAQMS) [*Pierce et al.*, 2003], which is a unified (stratospheric and tropospheric), multi-scale (global to regional) air quality modeling/data assimilation system with online chemistry. The Alaskan fire plume transected the DC-8 and MOSAIC flight paths during the campaign. Figures 8 and 9 compare RAQMS modeled CO with Atmospheric Infrared Sounder (AIRS) and Measurements Of Pollution In The Troposphere (MOPITT) column CO. RAQMS overestimates biomass emissions in comparison to satellite CO data, particularly near the fires. Flight tracks of the DC-8 and MOSAIC are shown in figures 10 and 11. Interestingly, RAQMS underestimates CO in comparison to in-situ flight data.







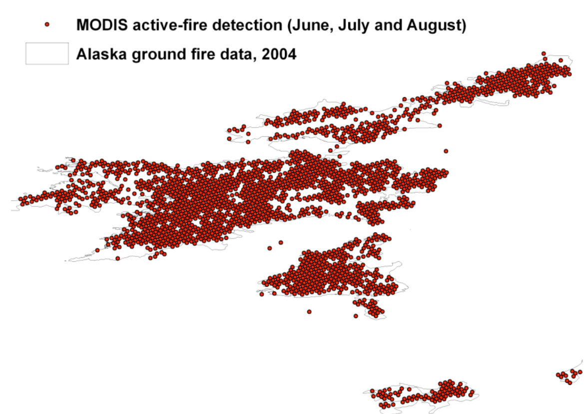


Figure 6. Ground-based fire data from the 2004 Alaskan severe fire season. These panels show random fire scars overlaid with MODIS fire detections, highlighting the spatial coincidence in these data.

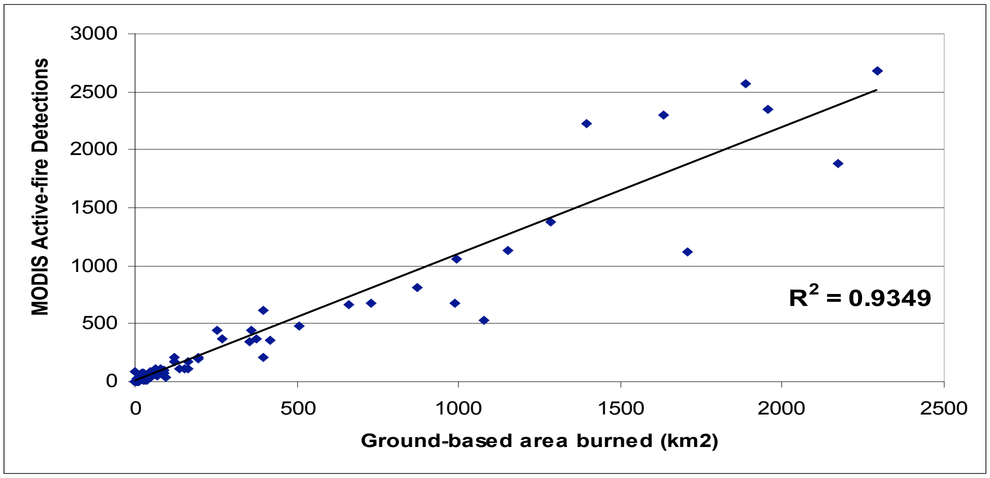


Figure 7. Comparison of area burned during the extreme 2004 fire season in Alaska.

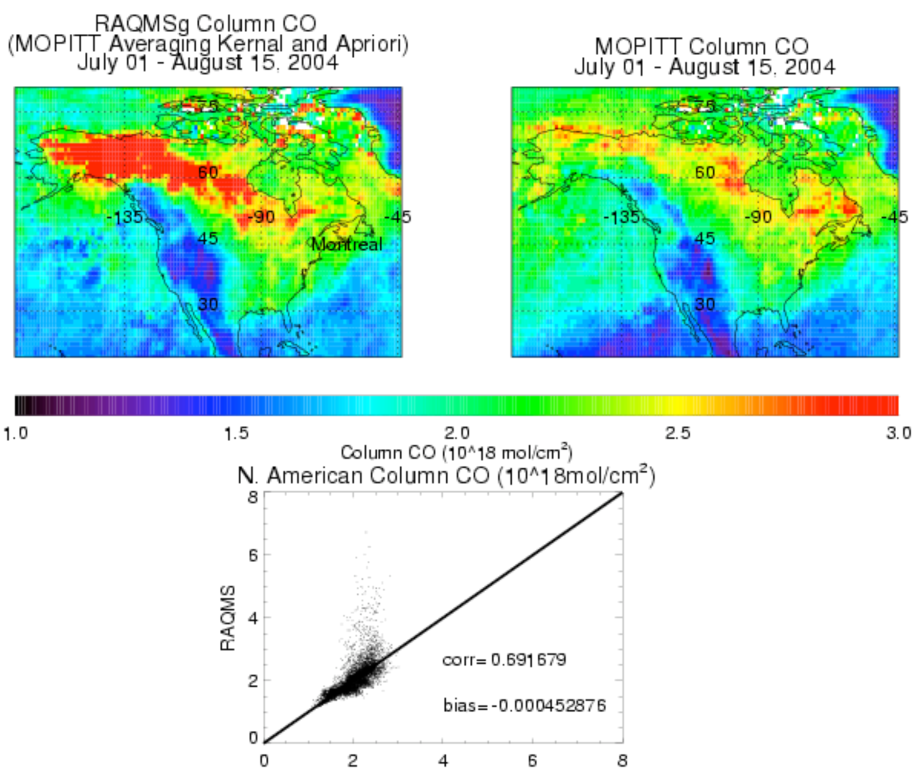
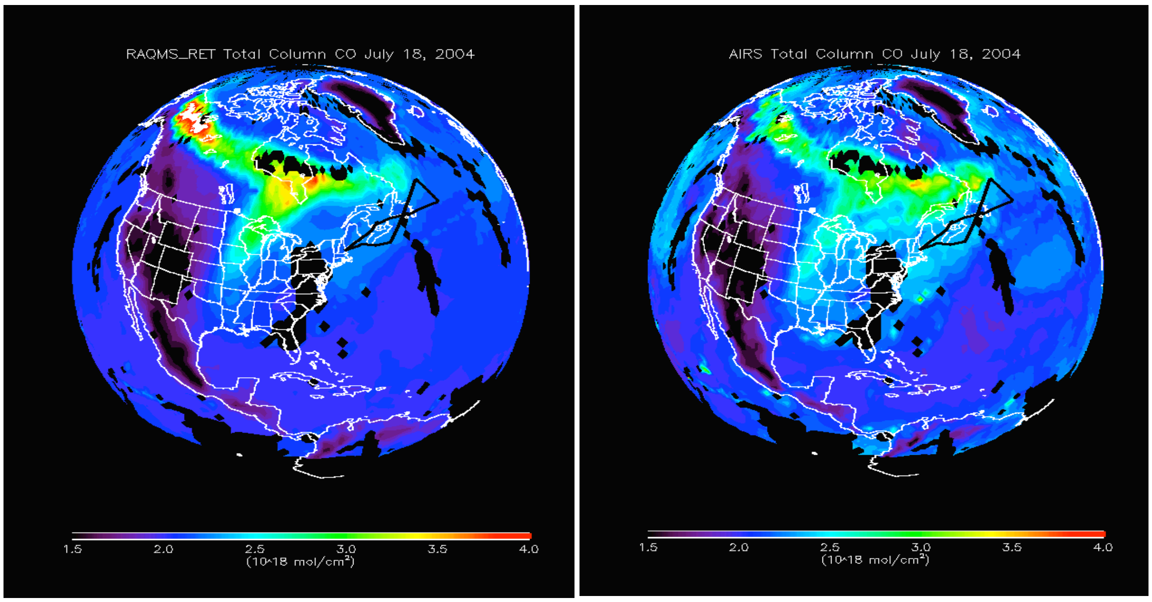


Figure 8. Comparison of MOPITT total column CO to RAQMS total column CO for the

North American boreal region during INTEX-A from July 1st through August 15th 2004. The bias is negative due to the underestimates of CO in the Pacific Ocean. RAQMS overestimates CO in comparison to MOPITT, particularly in the near field.



a. RAQMS CO column for July 18, 2004. b. AIRS CO column for July 18, 2004.

Figure 9. The RAQMS CO column is sampled at AIRS observation points and times. The RAQMS column overestimates CO relative to AIRS. The AIRS column is advected farther to the east, closer to the DC-8 flight path (shown in black), and further south and southeast as well. Advection differences could offer a partial explanation for the column differences.

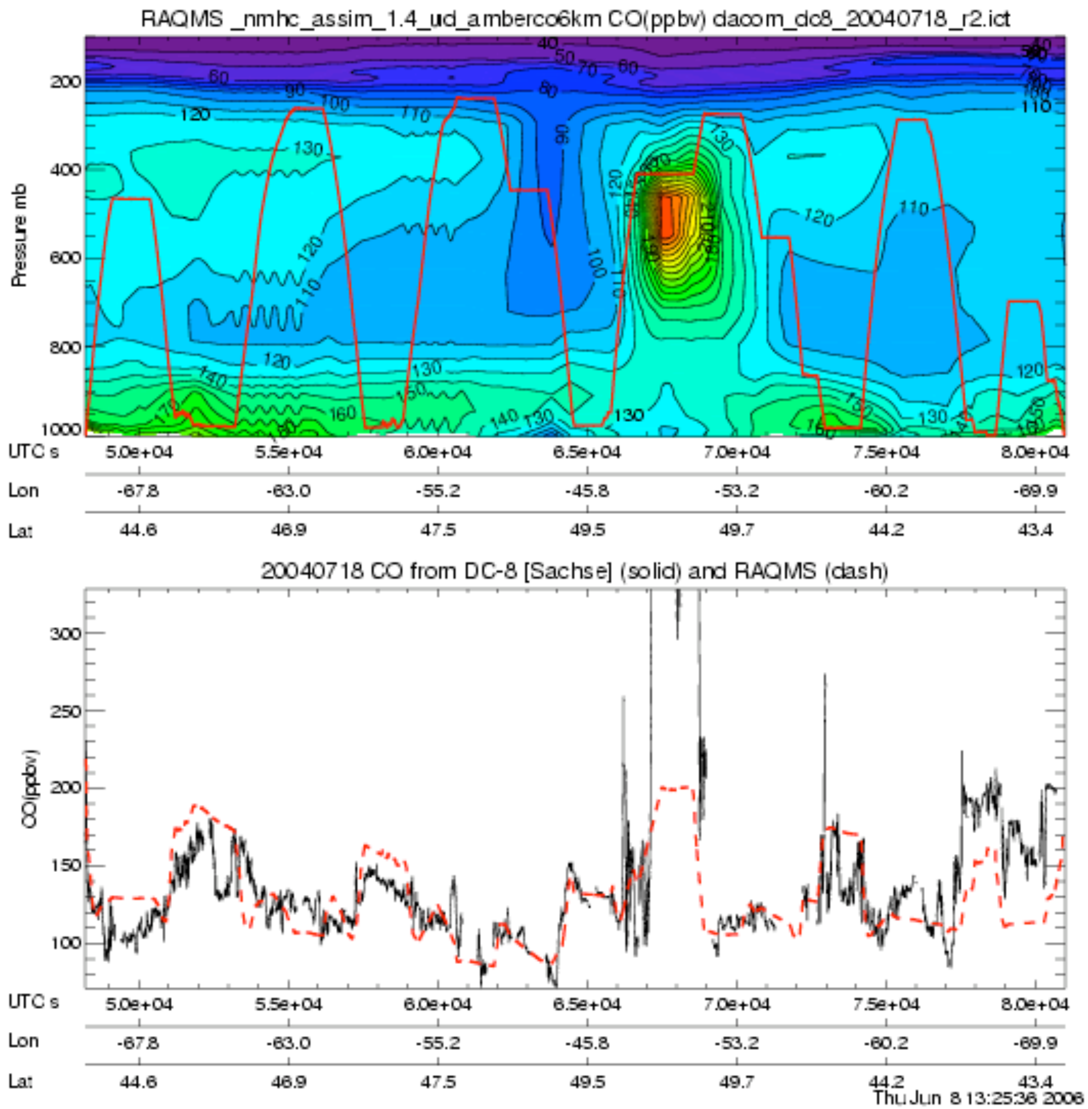


Figure 10. RAQMS versus in-situ CO data from the NASA DC-8 aircraft for July 18, 2004. The redline in the RAQMS curtain is the DC8 flight track. In general, the RAQMS and in-situ data coincide, with the exception of heavy plumes, particularly the plume encountered at about 6.8e+04 UTC. The RAQMS model depicts the peak of this plume slightly lower in the atmosphere than the aircraft flight track, which could be a partial reason for the RAQMS underestimate. Even so, RAQMS still underestimates (red center ~ 270 ppb) in comparison to in-situ data. Also, it must be noted that RAQMS is a 1.4° x 1.4° model, so the plume would be dispersed throughout this area.

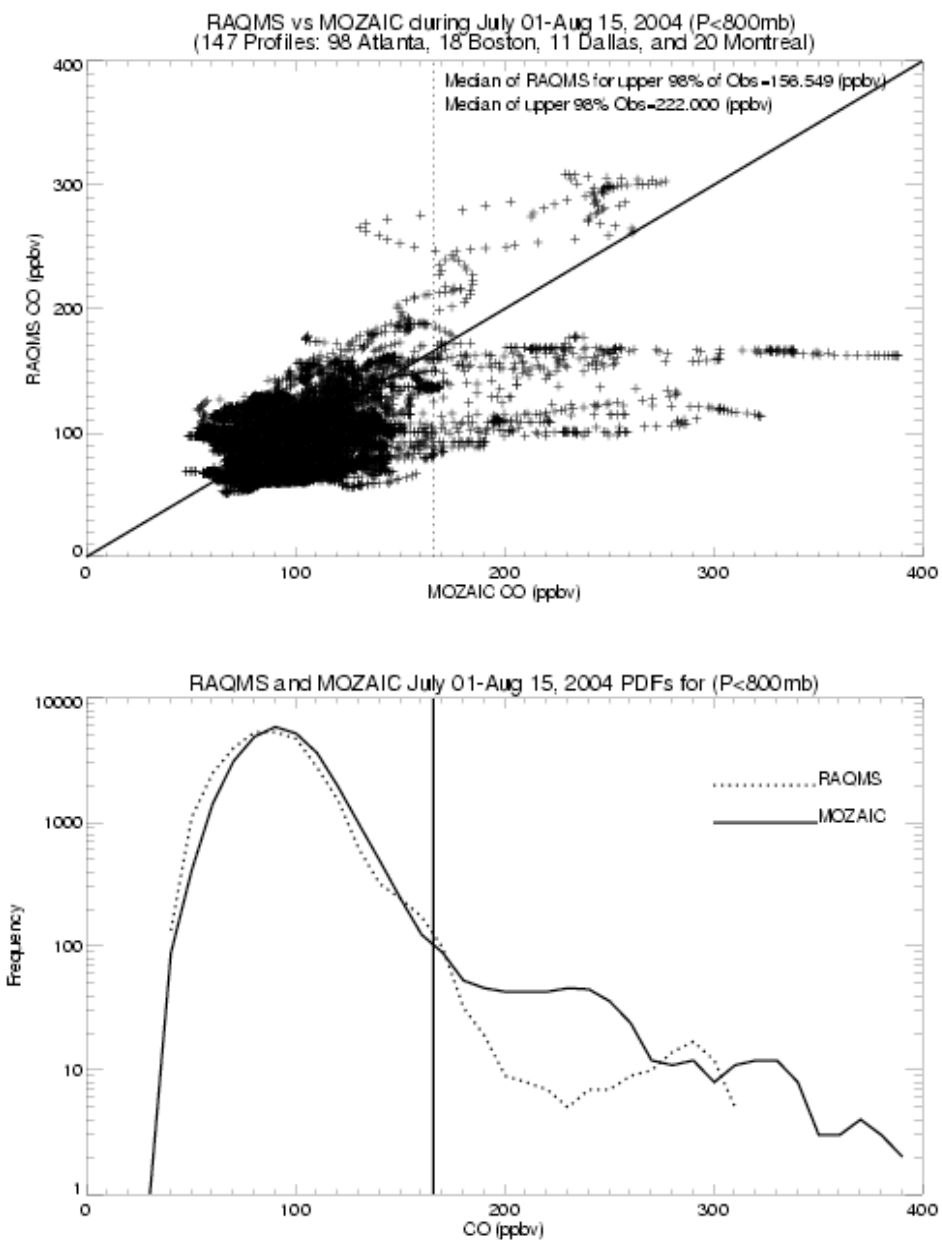


Figure 11. Comparison of 147 MOZAIC ascents and descents to coincident RAQMS model simulations. The probability density function provides a phase independent estimate of the agreement between the two distributions and are less than 800mb in an effort to avoid urban pollution affects. The vertical line at about 165 ppbv represents the 98th percentile of data points, and the data points that cross this line distinguish smoke

plumes. With the exception of 2 of 147 flight paths over Montreal on July 21st 2004, 12 UTC (RAQMS > 1:1 line), RAQMS tends to underestimates smoke plumes in comparison to in-situ data.

A Methodology for Estimating Area Burned

Terra and Aqua capture unique fires because of unique overpass times and GOES captures small agricultural fires that are not likely to be burning at MODIS overpass times. Both MODIS instruments overestimate area burned in CONUS, and GOES instantaneous area underestimates area burned. However, when combining the instruments, area burned is severely overestimated. The conundrum is that to accurately capture all fires, one must use all the instruments.

To address this problem using lessons learned from this and previous work, we generated a cumulative satellite product that takes input from Terra, Aqua and GOES. First, Terra and Aqua are buffered with a 0.50 km diameter (0.79 km^2). Then the MODIS instruments are combined into one aggregated MODIS data product, eliminating detection overlap. An example of the resulting product is shown in Figure 12. Comparing this result from the Biscuit fire (July 2002 burning only) to that shown in Figure 3 illustrates the improvement in the area burned estimate for this fire. MODIS fire detections overestimate area burned by 256%, and GOES cumulated instantaneous area estimates only 51% of the area burned. In contrast, the buffered MODIS area overestimates the area burned in this fire by only 6%. Also, the natural fire perimeter is captured with MODIS data, and this benefit is not available in the point-based ground data.

For Oregon, after buffering, combining and aggregating the MODIS data, the total area burned defined by this product is 87.5% of all the area burned (agricultural and non-agricultural). Remembering that GOES data accurately describes agricultural burning in space and time but only 1/5 of the area burned, GOES agricultural area burned is increased 5 times. This products represents 99.83% of the total area burned by agricultural fires in Oregon in July, 2002. Incorporating both the MODIS and GOES data products results in a satellite-derived fire product that quantifies 92% of the total area burned (agricultural and non-agricultural).

Finally, this methodology is used to quantify area burned in the vastly different ecosystem of Arizona. One difference is there are no coincident agricultural fires. However, because a large portion of the area burned is non-federal rangelands, and there is confidence in the season and amount of area burned, this area is necessarily included. The aggregated MODIS product defines 81% of the total area burned in Arizona for August and September. Because fire detections are available in Near-Real-Time (NRT), this methodology lends itself to emissions and pollution forecasting, similar to that shown in the Alaska example. Paired with a Land Cover map to identify agricultural land, this is a powerful methodology for estimating fire emissions in NRT.

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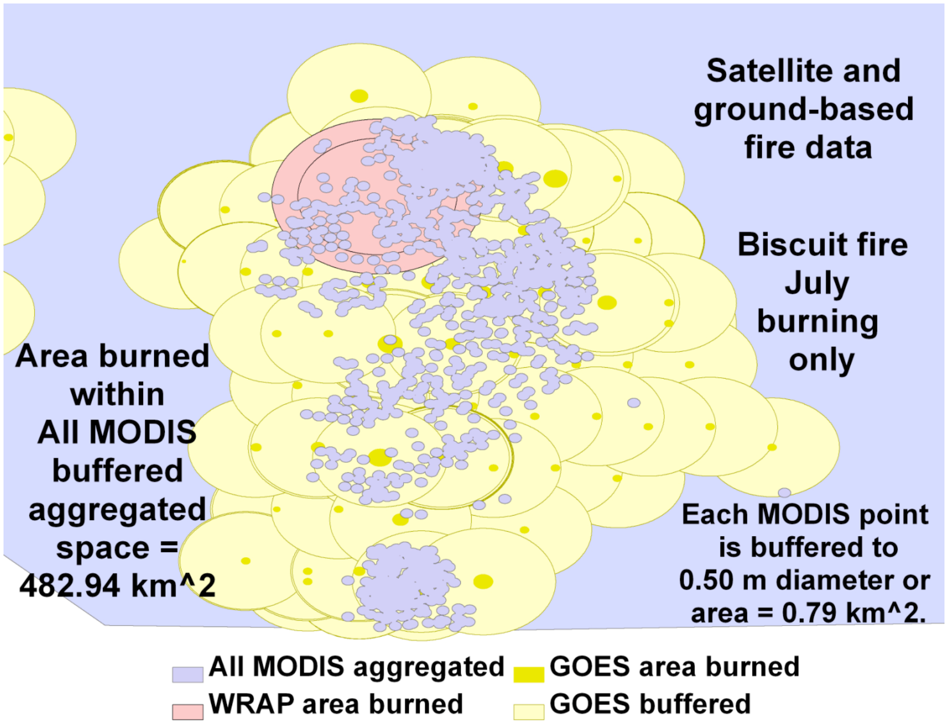

Figure 12. Buffered and aggregated MODIS (Terra and Aqua) data product. Total area burned within the buffered space for the Biscuit fire in July is 483 km^2, which is only 6% greater than that reported (see Figure 3). These figures and these analyses highlight the values of satellite data, however the limitations of these data must be considered. Fire detections, considered as 1km^2, generally overestimate area burned in CONUS.

Summary

The information provided in this report is based on year of analysis and not intended to completely describe methodologies or investigations, however these manuscripts are cited throughout this report. A synopsis of this benchmark report follows.

Each of the satellite instruments accurately define the spatial pattern of fire as it moves across a landscape in the continental United States, which is information that is not available in current ground-based data.

Each of the satellites is able to distinguish the largest fires, which accounts for most of the area burned and emissions. The combined satellite data (GOES instantaneous area, Terra and Aqua detections) are able to identify 97% of the representative coincident area burned in Oregon and 69% of the representative coincident area burned in Arizona. Representative area is the area reported burned in the WRAP data for each fire a satellite identifies.

There are inherent spatial and temporal errors in the ground-based data, which make it difficult to fully assess coincidence. When analyzing coincidence, Terra and Aqua are able to detect 10 and 12%, respectively of the total number of fires in Oregon in July, 2002. These numbers are low, because agricultural fires are included in this count. Again, if one considers a fire detection equivalent to 1 km^2, Terra and Aqua detect 126 and 94% of the total area burned by all fires, respectively. Conversely, GOES captures 34% of the number of all fires but only 37% of the total area burned. In Arizona, an ecoregion where it is difficult to detect fire, GOES identifies 5% of the total number of fires and 33 % of the total area burned. Terra and Aqua identify 15 and 12% of the total number of fires, respectively, but 141 and 139% of the total area burned, respectively.

However, if all the satellite data is consider (not solely coincident) without any type of scaling, Terra and Aqua detections substantially overestimate total area (~ 225 – 197%; if MODIS detect = 1 km^2) and GOES underestimates area burned (~ 62 - 77%).

In combination, all the satellites are able to detect 53% of the total number of fires and 262% of the area burned by all fires in Oregon. In Arizona, all satellites combined are able to detect 22% of the total number of fires. Nonetheless, combining these data results in an overestimate of the total area burned (220%).

In spite of its large-scale spatial resolution, GOES demonstrates an enhanced ability to detect small agricultural fires, which is a result of its geostationary orbit.

MODIS is able to accurately capture the number of fires (86%), amount of area burned (108%) and the spatial domain of large boreal fires in Alaska, 2004 with minimal error.

RAQMS modeled and transported, ground-based biomass CO emissions are overestimated in comparison to AIRS and MOPPIT satellite column CO data, however RAQMS underestimates CO in comparison to in-situ aircraft data. This information is helpful in improving biomass emissions estimates to RAQMS.

An approach is suggested and modeled that incorporates lessons learned from the preceding analyses. This model incorporates GOES and MODIS data, which are able to capture unique fires. Results indicate 92% of the total area burned in Oregon is captured (agricultural and non-agricultural) and 81% of the total area burned is captured in Arizona (includes non-federal rangelands).

Conclusion

This benchmark evaluated the ability of satellite-based fire data to quantify the frequency and amount of area burned compared to EPA ground "truth" data in an effort to enhance biomass burning emissions to the NEI. Limitations of the satellite data are highlighted and a methodology is suggested that incorporates both GOES and MODIS data to provide a complete assessment of fire (large fires to small agricultural).

Currently, the EPA depends on rigorous ground-truth fire data to estimate area burned and emissions, which is costly and takes years to prepare (2002 finalized in 2007). However, even this type of data can miss some fires, and the area burned is necessarily determined after the fact. In addition, most ground-based data is not of 2002 quality and will not be in the future. Although satellite data are not able to fully characterize the detail desired by the EPA (i.e. time a fire starts and ends, precise area burned on a small scale), it has a number of advantages. Satellite data can identify fire in a timely manner, which serves the EPA by enhancing the ability of the EPA to notify the public of an imminent fire-induced health risk. Moreover, satellite data accurately define fire perimeters as they progress across a landscape, and source location is essential for accurate modeling and the transport biomass burning emissions. Considering that firefighters are generally concerned with controlling fire, not area mapping for emissions, satellite data adds enhanced value to fire products. Additionally, accurate emissions estimates can be made available for general use almost immediately using satellite data. Also, because the EPA currently collects detailed ground fire data only once every 3 years, satellite data can be used to estimate emissions in the years where the detailed ground fire inventory data are not available. Considering the additional cost of detailed analysis (~ 1 million dollars, 24-36 months), these are substantial benefits.

The type of analysis presented in this investigation is essential to assigning potential error to satellite-based emissions estimates. Without these data, confidence in resulting emission estimates is limited. We suggest that satellite data could significantly improve biomass burning emission estimates by: (1) enhancing biomass burning emission estimates; (2) improving the temporal availability of emissions; (3) providing spatial information that was previously not available; (4) enhancing and improving estimates during times when detailed ground inventories are not available; and (5) enhancing and improving estimates in regions where temporal and/or spatial ground-based data is imprecise.

However, the most valuable accomplishment of this highly collaborative project is the EPA is incorporating satellite-based fire data in the 2005 inventory, the next year of concentration.

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